NAVAL FACILITIES ENGINEERING COMMAND
200 STOVALL STREET
ALEXANDRIA, VA. 22332

ÄÄ

SKID RESISTANT

RUNWAY

SURFACES

NAVFAC DM 21.9
DECEMBER 1981

ABSTRACT

Tbis design manual presents basic criteria for the design of skid resistant runway surfaces. Criteria are included on aggregate selection and mix design for skid resistant asphalt and portland cement concrete surfaces. Criteria are also included for determining surface friction coefficients using the Mu-Meter friction measuring trailer, and on maintaining skid resistant surfaces through periodic inspections and contaminant removal operations.

FOREWORD

This design manual is one of a series developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command, other Government agencies, and the private sector. This manual uses, to the maximum extent feasible, national professional society, association, and institute standards in accordance with NAVFACENGCOM policy. Deviations from these criteria should not be made without prior approval of NAVFACENGCOM Headquarters (Code 04).

Design cannot remain static any more than can the naval functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged from within the Navy and from the private sector and should be furnished to NAVFACENGCOM Headquarters (Code 04). As the design manuals are revised, they are being restructured. A chapter or a combination of chapters will be issued as a separate design manual for ready reference to specific criteria.

This publication is certified as an official publication of the Naval Facilities Engineering Command and has been reviewed and approved in accordance with SECNAVINST 5600.16.

W. M. Zobel
Rear Admiral, CEC, U. S. Navy
Commander
Naval Facilities Engineering Co

AIRFIELD PAVEMENT DESIGN MANUALS

DM No.	Superseded Chapters in Basic DM-21	TITLE
21.1*	l & 2	AIRFIELD GEOMETRIC DESIGN CRITERIA
21.2*	3	GENERAL CONCEPTS FOR PAVEMENT DESIGN
21.3	4	FLEXIBLE PAVEMENT DESIGN FOR AIRFIELDS
21.4*	4	RIGID PAVEMENT DESIGN FOR AIRFIELDS
21.5*	4	SOIL STABILIZATION FOR PAVEMENT
21.6*	4	AIRFIELD SUBSURFACE DRAINAGE AND PAVEMENT DESIGN FOR FROST CONDITIONS
21.7*	5	AIRFIELD PAVEMENT EVALUATION
21.8*	6	AIRFIELD PAVEMENT MARKING
21.9*	---	SKID RESISTANT RUNWAY SURFACES

*Under Development

CONTENTS

CONTENTS

FIGURES

CONTENTS

SKID RESISTANT RUNWAY SURFACES

Section 1. INTRODUCTION

1. SCOPE. There are numerous factors that can affect skid resistance of paved surfaces. This manual includes information and criteria for designing and maintaining skid resistant runway surfaces. Consideration is given to aggregate selection for various asphalt and portland cement concrete pavements. The importance of adequate geometric design and drainage, as well as construction methods, for achieving good skid resistant surfaces is discussed. This manual includes criteria for determining the coefficients of friction of runway surfaces using the Mu-Meter. The manual also includes criteria for maintaining skid resistant surfaces through routine inspections and contaminant removal operations.

2. RELATED CRITERIA. Additional criteria related to the design of skid resistant runway surfaces may be found in Flexible Pavement Design for Airfields, NAVFAC DM-21.3 and Airfield Pavements, NAVFAC DM-21.

3. DEFINITIONS. The definitions presented below are included to prevent misunderstanding and provide clarification of the various terms and factors relating to skid resistance.

a. British Pendulum Tester. The British Pendulum Tester is a dynamic pendulum impact-type tester used to measure the energy loss when a rubber slider edge is propelled over a test surface.

b. British Portable Number (BPN). The British Portable Number represents the frictional properties for flat surfaces and polish values for accelerated polishing-wheel specimens, as obtained with the British Pendulum Tester. ASTM E303 governs the determination of the British Portable Number.

c. Bulk Water. Excessive water accumulation on a runway surface which leads to runoff.

d. Coefficient of Friction (Mu). The ratio of the drag load acting on a tire to the vertical load acting on the tire at the same time. Generally used to rate the slipperiness of a pavement surface.

e. Differential Friction. Occurs when the wheelpaths in which a vehicle/aircraft rides have different values of coefficient of friction.

f. Flushing (Bleeding). The migration of excessive bitumen to the pavement surface as a result of poor mix design or densification of the wearing course under repeated heavy traffic. Flushing results in reduced surface texture and low values of friction coefficients.

g. Hydroplaning. Hydroplaning is generally classified as either viscous, dynamic, or reverted rubber hydroplaning. Viscous hydroplaning results in loss of tire traction due to the presence of a thin film of water in the tire pavement interface. Dynamic hydroplaning results in a severe loss of traction due to the rolling tire being supported on a layer of water. Complete dynamic hydroplaning can force the tire to stop rolling and lose complete contact with the pavement surface. In reverted rubber hydroplaning the water is superheated causing the tire rubber to melt or revert back to its natural state.

h. Macrotexture. Roughness of the pavement surface as a whole. Influenced by the course aggregate in asphalt surfaces and the texture finish in concrete pavements.

i. Microtexture. Fine-scale roughness contributed by individual small asperities of aggregate particles on pavement surfaces which may not be discernible to the eye, but are apparent to the touch (grittiness).

j. Mu-Meter. A three-wheel vehicle that measures the side force friction generated between the pavement surface and two pneumatic tires which are set at a fixed toe-out angle of 7-l/2 degrees to the line of drag.

k. Side-Slip Force. The transverse force developed at the tire-pavement interface when the wheels are turned so that they make an angle with their original path. The angle of the wheel path with the direction of motion is the slip angle, and the force is the side force.

l. Surface Contamination. Foreign material such as water, snow, dirt, dust, oil, rubber, etc., on a pavement surface which causes a reduction in surface friction.

Section 2. DESIGN AND CONSTRUCTION OF SKID RESISTANT PAVEMENTS

1. AGGREGATE CHARACTERISTICS. Aggregates considered for use in airfield pavement mixes should be selected on the basis of superior skid resistant qualities. Aggregate characteristics which influence skid resistance include resistance to polish and wear, texture, shape, and size.

a. Polish/Wear Resistance. As the aggregates in a runway surface come into contact with the aircraft tire under repeated traffic movements, the exposed aggregate will experience a wearing or abrasive effect. This effect is expedited by the presence of sand or grit on the runway surface. If the aggregates are of a particular nature, the gradual wearing will result in a loss of angularity of the aggregates and polishing may occur. As this happens, the overall skid resistance of the runway decreases. Aggregates selected for use in airfield pavement mixes must be able to withstand repeated heavy loadings without undue polish/wear. Some aggregates exhibit the ability to resist this polish/wear action more than others. Figure 1 provides a grouping of different materials according to their wear and polish characteristics. The groupings of materials listed in Figure 1 will provide satisfactory skid resistant qualities. Aggregates with course grain sizes and large differences in grain hardness lead to differential wear and breaking off of grains resulting in a constantly renewed abrasive surface. Rocks high in silica content perform

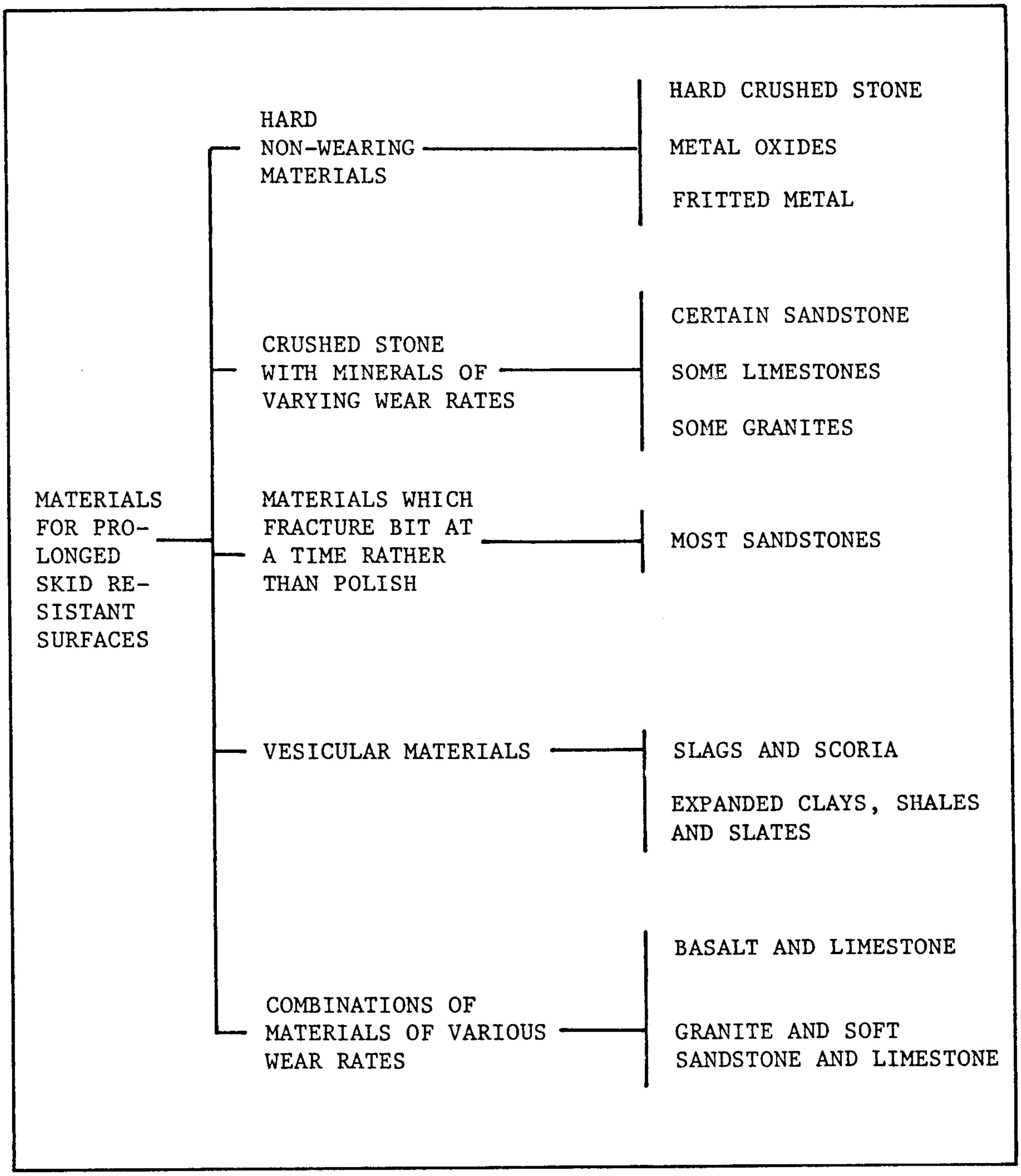


FIGURE 1

Aggregate Materials for Prolonged Skid Resistant Surfaces (NCHRP Synthesis of Highway Practice 14, Skid Resistance, 1972) more satisfactorily than those high in carbonate content. Figure 2 shows a ranking of various aggregates according to final friction factor after laboratory polishing. Fine grained aggregates such as oolitic limestone consisting essentially of pure calcium carbonate are poor performers. Rocks with high silica content such as sandstones, granite, and diabase are satisfactory performers. Other acceptable aggregates include unweathered crushed quartzite, quartz, diorite, and granodiorite.

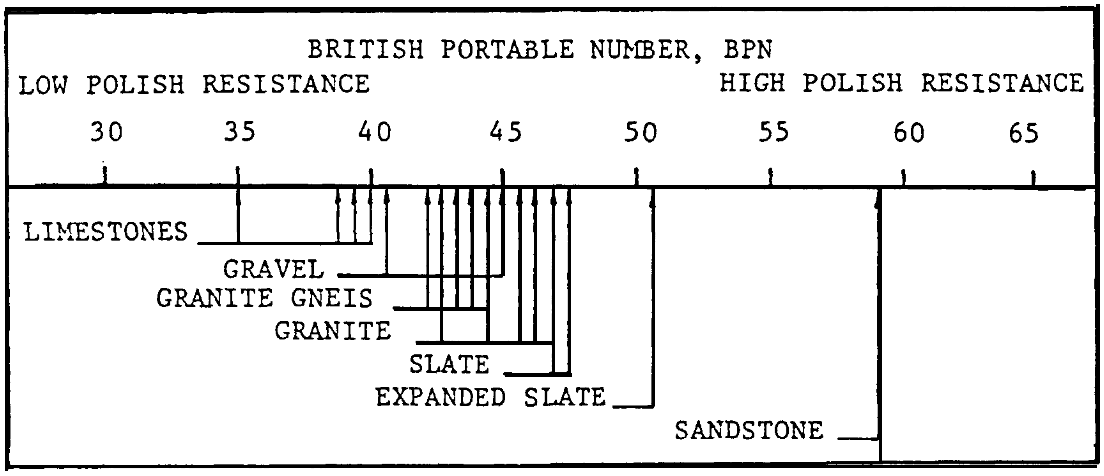


FIGURE 2

Friction Factor of Various Aggregates After Laboratory Polishing
(NCHRP Synthesis of Highway Practice 14, Skid Resistance, 1972)

(1) Blending Aggregates. Polish resistance within individual aggregate particles is highest when an optimum percentage of hard and soft minerals is present. This can be extended to mixes so that the same benefits can be attained through blending of hard aggregates and soft aggregates. Laboratory evaluation of limestone and silica gravel blends and crushed glass and limestone, granite gneiss, and natural silica sand blends indicate the polishing of aggregate blends produces polish levels that reflect an averaging of individual aggregate polishing resistance in proportion to the percentages used. Thus it may be possible to improve marginal polish resistant aggregates to an acceptable level by blending appropriate percentages of high polish resistant aggregates. Aggregates considered for blending should be tested in accordance with ASTM E660. A range of aggregate blend percentages should be tested to determine the optimum blend for high polish resistance.

b. Texture. The surface texture of an individual aggregate is given by the size of individual mineral grains and the matrix in which they are bonded. Aggregates with larger-than-sand sizes of hard grains which are weakly bonded will wear under traffic and expose a continually renewed nonpolished surface. However, if the matrix is strong, the individual grains will be held tightly and consequently may be polished by traffic. The presence of surface contaminants (sand or grit), which are harder than the mineral grains, may act as an abrasive and polishing of the aggregate will be accelerated. To display satisfactory skid resistant qualities, the aggregate should contain at least two mineral constituents of different hardness in order to wear differently and expose new surfaces. High silica content aggregates and certain carbonate aggregates, containing more than 10 percent sand-sized mineral grains distributed in a weak matrix, will perform satisfactorily.

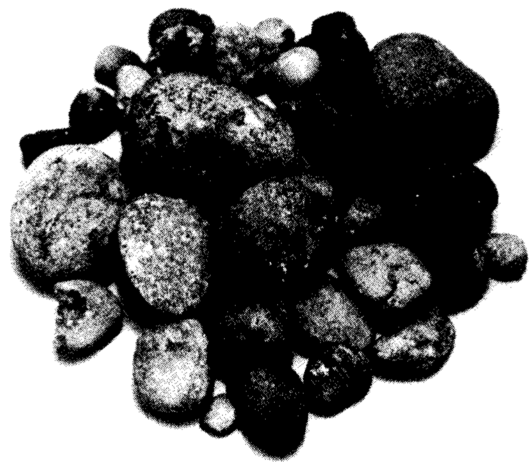
c. Shape. Aggregate particle shape significantly affects the skid resistance of the runway surface. Figure 3 shows the physical appearance of two types of aggregates. The aggregates in Figure 3A are rounded and exhibit no angularity. This type of aggregate will have poor skid resistance value. The aggregates in Figure 3B have sharp angular features which contribute to good skid resistance. Rounded aggregates considered for use in paving mixtures should be crushed before they are used. However, the retention of angularity is a function of the aggregate characteristics such as mineralogical composition and the amount of polish/wear produced by traffic. Some aggregates when crushed become flat and elongated, and as a result perform poorly.

d. Size and Gradation. The size and gradation of the aggregate must be considered in a pavement design. Generally, it is the larger-size aggregates that influence the skid resistance of asphaltic concrete pavement. This is particularly true for mixes such as porous friction courses where the aggregates are separated by void pockets to allow for water permeation. In portland cement concrete mix designs, it is the smaller, sand-size aggregate that controls the skid quality of the surface. During the paving operation, the small aggregates float to the top of the pavement structure and the combined sand-mortar mix becomes the wearing surface. Subsequent texturing of the plastic concrete (by broom or belt methods) provides a satisfactory skid resistant surface.

2. DESIGN OF PAVEMENT MIXTURES. A variety of pavement types are available for use as the wearing course on runways. These include portland cement concrete and dense and open graded asphaltic concrete. The skid resistance offered by any of these surfaces is greatly influenced by the choice of aggregates and the selection of the cementing agent used in the mix. Hence, the designer can control, to some degree, the ability of a pavement to exhibit satisfactory skid resistance. To achieve the best skid resistance qualities along with durability and strength, the designer may vary the following parameters of the design:

-- Aggregate type
-- Blending of aggregates
-- Size and gradation of the aggregates
-- Binder type and content
-- Texturing

a. Portland Cement Concrete. In the design of concrete pavements, consideration should be given to the fine aggregate which controls the grittiness of the surface texture and the method of finishing which controls the coarse texture of the surface.



(A) ROUNDED RIVER GRAVEL

(B) CRUSHED STONE

FIGURE 3

Comparison of Rounded and Angular Aggregate

(1) Mix Design Variations. The wearing surface of a concrete pavement generally consists of the cement mortar and smaller sand sized particles. Experience has shown that improved wear resistance in the pavement surface results from the following factors:

- -- Wear resistance of concrete increases as the cement factor is increased.
- -- Wear resistance of concrete increases as the water-cement ratio is decreased.

When designing a concrete mix for a pavement which will carry high traffic volumes or involve conditions that will subject the surface to highly abrasive action, the water-cement ratio should generally be lower than 0.50. A high water-cement ratio not only causes early concrete deterioration, but also encourages a buildup of surface mortar that is deficient in fine aggregate. Because the fine aggregate in the mortar has the greatest influence on pavement friction, it should have good wear/polish resistance and angular characteristics. To provide good skid resistance, the proportion of fine aggregate in the concrete mix should be near the upper limit of the range that permits proper placing, finishing, and texturing. It is possible to use less desirable aggregate for the coarse aggregate. However, if a pavement surface is of poor quality, the surface will wear and the coarse aggregates will eventually be exposed in sufficiently large amounts to overshadow the dominating role of the sand-mortar.

(2) Air Entrainment. Entrained air should be used in concrete pavements. Air entrainment protects the textured surface of the pavement from freeze-thaw effects and de-icing salts and provides the following additional benefits:

- -- Reduces segregation during placing operations
- -- Increases workability
- -- Reduces bleeding
- -- Reduces the amount of water required for satisfactory workability

The amount of entrained air needed to produce durable concrete is covered in NAVFAC NFGS 02613, Portland Cement Concrete Pavement for Roads and Airfields, and varies with the type of exposure the concrete will experience. Table 1 provides guidance on the amount of air entrainment needed.

TABLE 1
Choice of Air Content for Portland Cement Concrete

Maximum Aggregate Size, inches	Air Content Percent by Volume
3	4 ± 1.5
l-1/2 - 2	5 ± 1.5
3/4 - 1	6 ± 1.5

(3) Aggregates. Apart from construction techniques, such as plastic texturing, the siliceous particle content predominantly influences the skid quality of concrete pavement. Where economically feasible, a higher percentage of the smaller sized sand particles should be required. If suitable material is not economically available for use as the fine aggregate, alternate methods of achieving a skid resistant surface may be needed. These might include blending of fine (natural) aggregates with synthetic aggregates or applying wear resistant particles to the surface of the plastic concrete.

b. Asphaltic Concrete. The skid resistance of an asphalt pavement is influenced by the coarse aggregate. Therefore, it is important that the coarse aggregate be selected with consideration of the wear and polishing characteristics previously discussed.

Determining the optimum asphalt content is also an important phase in the design as it not only influences skid resistance, but also structural stability. If the asphalt percentage is too high, the asphalt will "flush" to the surface, covering the aggregate, and inhibiting skid resistance. If the percentage is too low, ravelling will occur, resulting in loose surface aggregates.

(1) Dense-Graded Asphalt Concrete. DM-21.3, Flexible Pavement Design for Airfields, covers the design and construction of dense-graded asphalt concrete pavement. A dense-graded asphalt course must prevent water penetration to the supporting layers, provide a smooth, well-bonded surface free from loose particles, and furnish a texture of nonskid quality. The aggregates should consist of crushed stone, gravel, or slag and in general, should not exceed a maximum size of 3/4 inch. Coarse aggregates should resist polish and wear. Blending of aggregate is possible where supply is scarce or when economically feasible. The surface texture for dense graded asphalt runways should be coarse and gritty. If the durability and stability criteria are met in the mix design, generally the skid resistance quality requirements will be met, except for limestone and coral aggregate, in some cases.

(2) Porous Friction Course. The porous friction course (PFC) is a thin asphalt concrete surface course with a thickness not to exceed 3/4 inch. It consists of an open-graded aggregate with bituminous binder. The open-grade (30 to 40 percent void content) allows water to rapidly drain from the surface and move to the adjacent shoulder. As a result, superior skid resistance is obtained. The following features are also characteristic of PFCs:

-- Minimization of hydroplaning effects during wet weather
-- Minimization of splash and spray during wet weather
-- Improved visibility of painted runway markings
-- Retardation of ice formation on the surface

The PFC is not considered a load bearing course. Its use must be restricted to structurally sound and impermeable pavements. The thickness of a PFC should be kept to a minimum to reduce any tendency of the course to densify or shove under traffic.

(d) Mix temperature and viscosity. Porous friction courses must be mixed at lower temperatures than conventional mixes to avoid excess drainage of the asphalt from the aggregate. At the same time the asphalt cannot be so viscous that it does not coat the aggregate properly. Select a mixing temperature that will give a viscosity of 275 +25 centistokes. This can be accomplished by evaluating the temperature-viscosity curve for the specific job asphalt. The mixing temperatures for the given viscosity range are lower than recommended for asphalt concrete.

(e) Drainage. The asphalt drainage test should be conducted to insure that excessive drainage of asphalt does not occur. Test for excessive drainage as follows:

(a) Prepare a 300-g sample of the mixture at the design binder content
(b) Place sample in a 6-inch diameter culture dish in an oven preset to the mixing temperature for 2 hours
(c) Remove sample and allow to cool

The amount of drainage at the bottom of the dish should not exceed 50 percent coverage. If the drainage exceeds 50 percent, either the mixing temperature or the binder content can be reduced.

(f) Additives. Rubber (neoprene) added to the mix improves the adhesion characteristics. The addition of a small amount of rubber also improves the basic asphalt properties, including increased resistance to aging, increased long-term elasticity, added strength, tenacity and toughness, low-and high-temperature stability, and increased resistance to flow. No more than l-1/2 percent by weight of asphalt of the rubber additive should be used. The mix should be rejected if heated above 340 degrees F.

3. GEOMETRIC DESIGN AND DRAINAGE. DM-21, Airfield Pavements, provides geometric design and drainage criteria for airfield pavements. The criteria for runway and shoulder slope are summarized in Table 4. In the geometric design of runway pavements, consideration should be given to minimize the amount of water that can accumulate on the pavement surface. Excess or bulk water, above that amount which can be removed by drainage, reduces skid resistance and increases the potential for hydroplaning. Varying rainfall intensities, pavement cross slopes, drainage length, and surface textures have significant effects on pavement water depths (see TTI Report No. 138-5, The Effects of Rainfall Intensity, Pavement Cross-Slope, Surface Texture, and Drainage Length on Pavement Water Depths). The experimentally determined equation relating water depth to surface texture, length of drainage path, rainfall intensity, and pavement cross-slope is:

$$d = \left[3.38 \times 10^{-3} (1/T)^{-.11} (L)^{.43} (I)^{.59} (1/S)^{.42}\right] - T \qquad (2)$$

WHERE:

d = water depth above top of texture (in)

T = average texture depth (in)
L = drainage path length (ft)
I = rainfall intensity (in/hr)
S = cross-slope (ft/ft)

The following results are apparent:

-- Increasing surface texture results in a decrease in water depth for a given rainfall intensity, cross slope, and drainage length. This effect is more pronounced at flatter cross slopes and lower rainfall intensities.

-- Greater drainage lengths increase water depth. However, the rate of increase in water depth becomes smaller as drainage length increases.

-- Greater water depths are associated with higher rainfall intensities.

-- Increasing pavement cross slope results in reduced water depth. This is very significant at the flatter cross slopes where a slight increase in cross slope results in a pronounced reduction in water depth.

Figure 4 is a hypothetical case which illustrates the application of equation (2).

a. Runway Crown. Runway pavements having continuous cross-slopes, without crowns, are particularly slow to drain and are susceptible to hydroplaning problems. Runway intersections, transition areas, and other areas where transverse grades tend to be flatter than 1% may also accumulate water. In such cases overlays should be designed to build up the center line and create a crowned section with a shortened drainage length. Where construction of a centerline crown may be impractical, an offset crown shall be provided.

All runways requiring an overlay shall be designed with a minimum of 1% transverse grade.

4. SURFACE TREATMENT AND CONSTRUCTION TECHNIQUES. Asphaltic concrete runways constructed by the methods outlined in DM-21.3, generally will maintain a skid resistant surface. While skid resistance can be achieved by proper mix design and drainage, it can be greatly enhanced by the introduction of sawed transverse grooves or a porous friction course. The skid resistance of portland cement concrete runways can be controlled to some degree at the time of construction. A finish is usually applied while the concrete is still in the plastic state. The finish provides the surface with an increased texture depth improving tire contact by providing sharp ridges of mortar that break through the water film on wet pavements. Surface texture produced by a finishing technique is usually short-lived, wearing away in a few years under repeated traffic movements, weather, and contaminant removal operations. Grooving has been used in

recent years to supplement the finish applied to new concrete pavements and to improve the skid resistance of older surfaces.

TABLE 4
Runway and Shoulder Slope Specifications

RUNWAY	
Minimum transverse grade	-1.0%
Maximum transverse grade	-1.5%
Maximum longitudinal grade	-1.0%
Longitudinal grade changes	0.167%/100 linear feet[1]
Note: All runway pavements must have crowned sections.	
SHOULDER	
Longitudinal grades	Same as Runway
Transverse grades	-2.0% to -3.0%[2]

Notes:

1. No grade change allowed within 3000 feet of runway ends.
2. For first 10 feet from runway edge. Unpaved shoulders may be increased to 5%.

Experience on a 200 ft. wide runway with cross slope of 1.5% and an average texture depth of 0.020 in. has indicated that a rainfall intensity of 1.5 in./hr. will cause dynamic hydroplaning.

No hydroplaning has been reported when the rainfall intensity is less than 1.5 in./hr.

What rainfall rate can be expected to cause dynamic hydroplaning on a recently constructed runway with the same specifications and an average texture depth of 0.045 in.?

T = .020 in.

L = 100 ft.

I = 1.5 in./hr.

S = .015 ft./ft.

$$d = [3.38 \times 10^{-3} (1/.020 \text{ in.})^{-.11} (100 \text{ ft.})^{.43} (1.5 \text{ in./hr.})^{.59} (1/.015 \text{ ft./ft.})^{.42}] - .020 = 0.098 \text{ in.}$$

For T = .045 in. and d = 0.098 in., I = 1.785 in./hr.

For the conditions stated, 125% increase in texture depth will result in a 19% increase in rainfall intensity before similar hydroplaning potential is duplicated.

FIGURE 4

Example Application of Rainfall Rate and Texture Depth Relationships.

a. Asphaltic Concrete Pavements

(1) Sawed Grooves. Conventional asphaltic surfacings may be grooved to improve skid resistance. The decision to groove an asphalt surface should be based on factors such as expected traffic movement, climatic conditions, and existing runway conditions. Prior to grooving, the runway should be thoroughly evaluated. Grooving should be applied only to runways which are structurally sound and free of defects such as bumps, depressed areas, cracks, and ravelling. Grooving of new asphaltic runways or runways newly resurfaced with asphalt should not commence until the asphalt surface has cured for approximately ninety (90) days. This curing period will allow the material to become stable enough to prevent closing of the grooves under normal use. Conditions may warrant an overlay or rehabilitation prior to grooving. Grooves applied to asphalt runways may close up and run together when they are subjected to repeated heavy loadings and extended periods of high ambient temperatures. Grooving of asphalt runway surfaces must be coordinated with, and approved by, NAVFAC Headquarters.

(a) Equipment. Grooving should be done utilizing diamond saw blades, mounted on amulti-blade arbor on a self-propelled machine which has been built for grooving of pavements. The groover should have a depth control device which will detect variations in the pavement surface and adjust the cutting head height to maintain the depth of the groove. The grooving machine should be provided with devices to control alignment.

(b) Groove pattern. Grooves should be continuous for the complete length of the runway and normal to the centerline for the length of the runway. The grooves should be terminated within 10 feet of the runway edge. Figure 5 illustrates the recommended groove pattern. The groove pattern should be l/4 inch wide x l/4 inch deep with center to center spacing of l-1/4 inches. The grooves should be evenly spaced not less than l-1/8 inches or more than 2 inches. The depth and width of groove shall have a tolerance of plus or minus l/16 inch. The grooves should be parallel and perpendicular to the centerline of the runway with allowable variation from the perpendicular limited to plus or minus l-1/2 inches in alignment for 75 feet.

(c) Limitations. Extreme care should be exercised when grooving near in-runway light fixtures and wireways. Grooving should be terminated a minimum of 2 feet from existing light fixtures.

(d) Clean-up. Slurry resulting from the grooving operation should be continuously removed. Pavement must be left in a clean condition, free of all the slurry. All debris and surplus material from the grooving operations should be disposed of in an area off the edge of the paved surface. Grassed areas with a slurry buildup of over 1 inch should be raked and spread out so that buildup does not exceed 1 inch. Slurry removed from the runway and shoulders should not be allowed to enter storm sewer inlets.

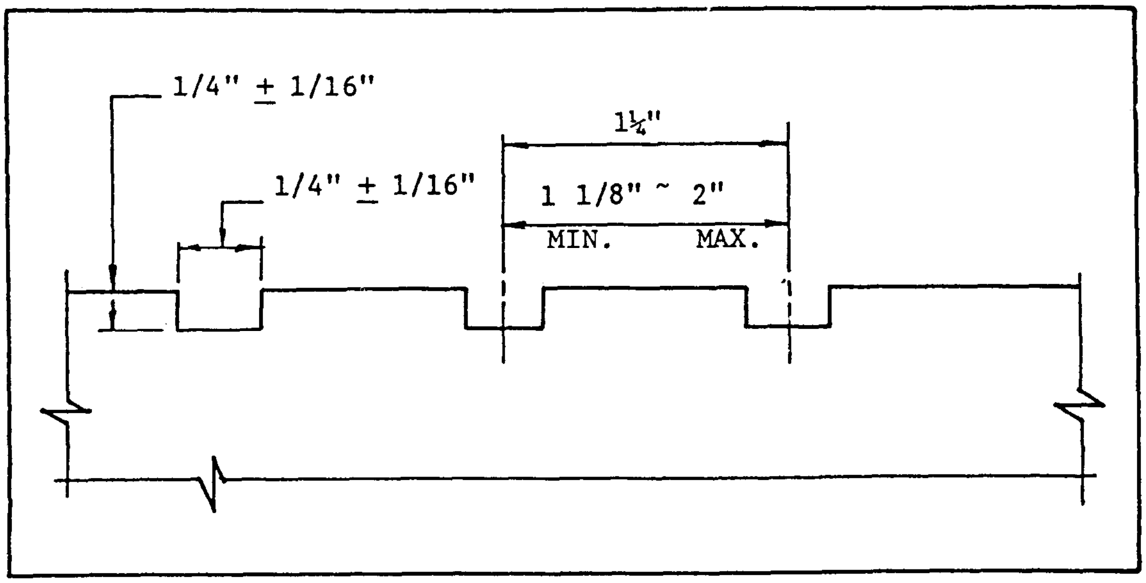


FIGURE 5

Recommended Groove Pattern
(DM 21.3 Flexible Pavement Design for Airfields, 1978)

(e) Contaminant removal. Contaminant deposits in grooves, resulting in reduced skid resistance, is the most serious maintenance problem. Grooving effectiveness is demonstrated by the ability of the grooves to remove water from the runway surface. Grooves clogged by rubber deposits, dust, dirt, etc., become non-effective. Contaminant removal operations should be scheduled regularly at high-use air stations.

(2) Porous Friction Course. Mix design considerations for porous friction courses are covered in paragraph **2.2.b.(2).** A porous friction course should be constructed only on a dry surface when the atmospheric temperature is 500F and rising (at calm wind conditions) and when the weather is not foggy or rainy. The base pavement must be clean with no distress manifestations, such as rutting, severe cracking, or depressed areas. Cracks in the base pavement will reflect through the porous friction course and lead to ravelling. Low spots in the base pavement will cause the porous friction course to hold water. Cross slope must be sufficient to allow water to drain laterally across the pavement onto the shoulder. Porous friction courses are constructed with conventional laydown and construction equipment. Since the open texture and thin layers promote rapid cooling, compaction should follow immediately after laydown. Do not overcompact as aggregate degradation and reduced permeability may result.

(a) Limitations. Some degradation has been experienced on friction courses as a result of jet blasts, aircraft turns, and fuel spills. To limit the **susceptability** of the friction course to these exposures, the course should not be permitted in the last 1,500 feet the runway or in the vicinity of arresting gear cable.

b. Portland Cement Concrete Pavements

(1) Finishing New Concrete Pavement. Many techniques have been used to produce finishes in concrete pavement surface, such as burlap drag and broom, wire comb, brush, or belt finishing. Since runways generally require deeper than normal textures for improved skid resistance, the mix design should be such that the deeper ridges of mortar have sufficient strength to resist wear. A very stiff mix (low slump) is required for slip form paving. Burlap drag finishing has not been shown to produce textures which are deep enough or durable enough to enhance the skid resistance of slip form paved runway surfaces. However, a burlap drag preceding plastic grooving or sawed grooving is acceptable. Superior results have been obtained using a broom finishing technique. This technique is recommended for use on all newly constructed runways. The following criteria should apply for finishing new concrete pavements.

(a) Texturing. Texture characteristics are related to the concrete mix, the water-cement ratio, and time elapsed before finishing begins. Timing is a critical phase of the finishing operation. If the finish is attempted too early, the mortar will be too wet and will not hold its shape. If the finish is applied too late, the mortar will be too dry and will crumble and break away under the finishing operation. Environmental conditions such as wind, humidity, and temperature also affect the texturing process. The best results are obtained when the finish is applied just before the water sheen has disappeared and before the pavement becomes nonplastic. Texturing equipment should be operated transversely across the pavement surface. Care should be taken not to tear or unduly roughen the pavement surface during the operation. If it is apparent that the surface is drying too rapidly, a light fog spray may be applied to the surface. The equipment should be cleaned regularly to prevent excessive grout buildup. Curing should begin immediately after the water sheen has disappeared following the texturing. Care should be taken not to damage the textured surface.

(b) Burlap drag. Finish the surface of the pavement by dragging on the surface a strip of clean, wet burlap measuring from 3 to 10 feet long and 2 feet wider than the pavement. Select the dimension of the burlap drag so that at least 3 feet of the material is in contact with the pavement. Drag the surface in such a manner to produce a finish with a fine granular or sandy texture without leaving disfiguring marks.

c) Broom finish. Manual brooming should be accomplished by drawing the broom from edge to edge of the pavement with adjacent strokes slightly overlapping. The corrugation produced should be uniform in appearance and should not be greater than l/16-inch in depth. Brooms should have stiff bristles and be of appropriate quality, size, and construction. Mechanical brooming may be substituted for manual brooming provided a test section application yields acceptable results. The broomed surface should be free from porous spots, irregularities, depressions, and small pockets or rough spots such as may be caused by accidentally disturbing particles of coarse aggregate embedded near the surface.

(2) Plastic Grooving New Pavement. After surface irregularities have been removed, give the concrete surface a uniformly roughened finish by use of a wire comb or other approved texturing device similar to a wire comb. Prior to plastic grooving, one pass should be made with a burlap drag in the longitudinal direction. A texturing machine with a wire comb should be used to execute uniformly spaced corrugations in the transverse direction. Select a wire comb at least 10 feet long with polished tempered spring steel tines, 4 inches long, l/8 inch in diameter and spaced l/2 inch apart, securely mounted in a rigid head and positioned in a straight line parallel to the longitudinal centerline of the head. Form grooves perpendicular to the centerline of the pavement and in a straight line. Carefully align the successive passes of the machine and texturing device to obtain a continuous textured surface made by the comb. The grooving should be completed while the concrete surface is in such condition that it will not be torn or unduly roughened, and before the surface has obtained its initial set. Clean or replace the grooving device as often as necessary to obtain the required surface texture. Select the time of texturing to produce the required finish. Pull the tines across the pavement surface as the water sheen of the fresh concrete begins to disappear, and at a speed slow enough so that the tines will produce grooves l/l6 to l/8 inch deep and l/8 inch wide spaced on l/2-inch centers. After texturing, the pavement surface should be uniform in appearance and free from surplus water, rough or porous spots, irregularities, depressions, and other objectionable features. Do not indiscriminately specify wire combing for all new concrete runway and taxiway construction. When applied to high slump concrete this technique may produce ridges of slightly bonded particles which when loosened may cause damage to aircraft engines. Wire combing should not be used for short sections of runway construction in which a large variation in texture over the adjacent runway sections will be created.

(3) Grooving Existing Pavements. Sawed grooves may be installed in existing portland cement concrete pavements or new concrete pavements that have been properly cured (minimum of 15 days). Grooves should not be cut closer than 3 inches to transverse contraction joints. Grooving should only be considered for pavements which are structurally sound. An evaluation should be made of the entire runway surface. Rubber buildups should be removed prior to grooving. Grooving should not be performed on distressed concrete pavements until faulted joints and cracked or spalled areas are repaired or replaced. Compressive strength tests should be made on selected cores taken from the runway pavement and the runway should be evaluated for current and future aircraft loadings. The installation of sawed grooves for all portland cement concrete pavement should be carried out in accordance with the guidelines specified in paragraph 2.4.a.l.

5. RESTORATION OF SKID RESISTANCE. If there is reason to believe the friction characteristics of a runway have deteriorated beyond acceptable limits, corrective action should be taken to restore the surface friction qualities. A program of routine inspections and gradient measurements will assist in determining the skid resistance quality of a runway. Skid resistance of asphalt pavements may be restored by application of a slurry seal as an interim measure before an overlay is constructed.

a. <u>Routine Inspections</u>. Periodic inspection should be made of runway surfaces to determine any possible loss in skid resistance. Specific items to watch for include pavement surface contamination, inadequate surface drainage, and excessive wear of the surface texture. Existence of any one of these items should be corrected.

(1) Pavement Surface Contamination. Contaminant buildup on runway surfaces is the major contributor to wet weather skidding accidents.

(a) Dirt, oil, and fuel. Contaminants such as dirt/dust particle deposits generally are washed away by the weather or blasted away by aircraft engines. Oil and jet fuel spillage is more prevalent on parking aprons than runway surfaces due to the short use time of the runway by aircraft. However, any excessive fuel or oil that is spilled on the runway should be removed immediately. On asphaltic concrete pavements, fuel spillage can weaken the asphalt binder and cause ravelling .

(b) Rubber. Rubber deposits are common to all runway surfaces and adversely affect runway friction characteristics. Figure 6 shows the reduction in coefficient of friction due to rubber deposits and paint marks on a runway. If inspection reveals areas of heavy rubber buildup, measurements should be made of the average surface texture depth. Appendix C provides guidance in the measurement of surface texture depth using the NASA Grease Smear technique. When the texture depth is less than 0.016 in. in rubber areas, there is potential for hydroplaning.

c) Rubber removal methods. Several methods have been experimented with to remove rubber buildup from runway surfaces including:

<u>High Pressure</u> Water
- -- successfully used
- -- economical
- -- may contribute to polishing

<u>Sandblasting</u>
- -- effective but removal rates are slow
- -- costly
- -- requires long runway closure time
- -- contributes to air pollution
- -- may cause degradation of pavement surface

<u>Grind ing</u>
- -- successfully used
- -- usually results in some damage to the pavement surface

<u>Chemicals</u>
- -- less used because of possible contamination of local water sheds
- -- could have adverse effect on the pavement surface

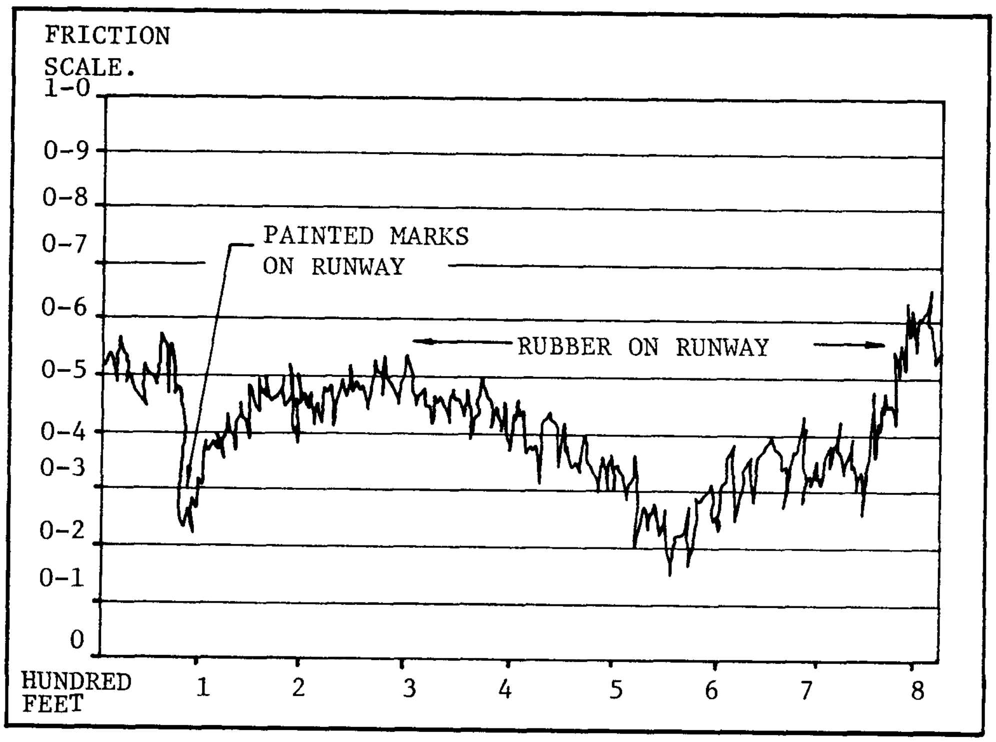


FIGURE 6

Reduction of Runway Friction Due to Surface Contamination (NASA-TN-D-6098, A Comparison of Aircraft and Ground Vehicles Stopping Performance on Dry, Wet, Flooded,-Slush, Snow, and Ice-Covered Runways, Langley Research Center, 1970)

High-Pressure Water-Jet Removal of contaminants is the preferred method of removal. This method of contaminant removal consists of applying high pressure water (in the range of 5000 to 8000 psi) to the runway surf ace. High pressure water removal methods used in the U.S. have proven successful in removing the majority of rubber deposits on most runway surfaces and increasing friction values. However, no suitable method of removing rubber deposits on porous friction courses has been determined. Generally less rubber buildup occurs on porous friction courses than on conventional pavement surfaces. High pressure water removal methods have been proven successful, but their use may be detrimental to the porous friction course. Contracts for rubber removal should specify 95 percent of all visible rubber.

(c) Paint markings. Painted surfaces in the touchdown and centerline areas should be stripped of the old paint and repainted after five consecutive remarkings have been applied. High-pressure water cleaning has proven successful in removing paint from runway surfaces. Contracts should specify removal of 80 to 85 percent of built-up paint.

b. <u>Gradient Measurements.</u> Water buildup on runway surfaces is of primary concern since it directly relates to hydroplaning potential. The ability of a pavement to drain bulk water is largely dependent on its transverse slope. As part of the routine inspection, transverse and longitudinal slope measurements should be made at 500 foot intervals and at runway intersections. Gradient measurements not only reveal the overall drainage ability of a pavement, but also help determine areas susceptible to ponding.

(1) Equipment. Slopes may be measured fast and accurately using a specially designed bar. The bar is a 10 foot x 3 inch x 3/4 inch rectangular section with five machinists levels attached. In lieu of this slope measuring device, a surveyors level and rod may be used. All cross slopes should be measured to within 0.1 percent.

C. <u>Asphalt Slurry Seals.</u> Runways considered for a slurry seal treatment may require some surface improvements, but should have no serious structural defects. Slurry seals should not be considered as a structural pavement rehabilitation. Asphalt slurry seals may be used as an emergency measure to improve the skid resistance of an asphalt pavement. Slurry seals are adequate for two to three years depending on the condition of the old surface and the traffic volume.

(1) Design and Construction. The asphalt slurry seal should be designed and constructed in accordance with NAVFAC TS-02674, <u>Asphalt Slurry Seal</u>.

(a) Aggregate. The aggregate should consist of sound durable crushed stone or crushed gravel, and approved mineral filler. Aggregates should be 100 percent crushed and conform to the gradation shown in Table 5.

TABLE 5
Aggregate Grading Requirement for Slurry Seal

Sieve Size	Percent Passing
3/8-inch	100
No. 4	90-100
No. 8	65-90
No. 16	45-70
No. 30	30-50
No. 50	18-30
No. 100	10-21
No. 200	5-15

The gradation should be determined in accordance with ASTM C136 and C117. The maximum percentage of wear should be not more than 30 when tested in accordance with ASTM C131, Grading D. When tested in accordance with ASTM D2419, the aggregate, excluding the mineral filler, should have a sand equivalent of not less than 45 excepting that the minimum sand equivalent shall be 60 when used with a cationic or quick-set emulsion.

(b) Emulsified asphalt. The emulsified asphalt should be anionic type SS-lh, conforming to ASTM D977, cationic type CSS-lh, conforming to ASTM D2397, or Quick Set grade. Bidding contractors should be permitted the use of either anionic or cationic emulsions, depending upon the available sources and the availability of aggregate type. Generally cationic emulsion (CSS-lh) provides better adhesion to acidic aggregates such as silicates and is suited for general application in most parts of the country. Cationic emulsions cure at a faster rate than anionic and are more suitable in damp or highly humid climates. Anionic emulsion (SS-lh) is generally more suitable with basic aggregates such as limestone. Quick-Set grade emulsions have no universal designation and vary with manufacturer. Where Quick-Set grades are commonly used, reference the appropriate local or state specification. The type of emulsion to be used with any particular aggregate must be verified by the wet track abrasion test. The asphalt emulsion content and aggregate weight per square yard should conform to the following requirements:

Asphalt Emulsion Content, Percent of Aggregate by Weight	16 ± 3
Pounds of Aggregate per Square Yard	13 ± 2

c) Quality control. If improperly mixed and placed slurry seals may tend to ravel prematurely and create a loose aggregate condition. To assure satisfactory performance the application rates in the field must be consistent with the mix design as determined from the wet track abrasion test (See NAVFAC TS-02674, Asphalt Slurry Seal). The slurry mixture must contain only the minimum amount of water necessary to obtain a fluid mixture without segregation of the aggregate.

l.GENERAL DESCRIPTION OF THE MU-METER.The Mu-Meter (see Figure 7) is a light-weight 3 wheel trailer unit designed by M.L. Aviation Co. to measure the surface friction conditions of pavements. The unit consists of a triangular frame with 2 friction test wheels and a rear wheel which drives a recorder and stabilizes the machine, a ballast, a transducer, and a recording mechanism. In the operating condition the test wheels are set at a fixed toe-out angle of 7-1/2° to the line of drag. When pulled over a runway surface, the Mu-Meter continuously records the side-slip force between the surface and test wheels.

a. <u>Mu-Meter Equipment</u>. Among the optional equipment available: an Automatic Print Out Unit, a Remote Wheel Position Change, and a Self-Watering System. When incorporated into the standard Mu-Meter these modifications allow for quick data reduction and easier operation.

(1) Automatic Print Out Unit. The Automatic Print Out Unit (APU) is available to supplement the graphic record. The APU is a computer which directly replaces the Remote Read Unit and accepts the same input and power supplies. The APU calculates the average friction for each test section distance covered and visually displays it and prints it on a tape for permanent record. Events may be denoted by pressing an Event Marker button. The APU is operated as follows: The Mu-Meter is accelerated to the correct speed. Upon entering a test section, the compute button is pressed. At the end of the section, the button is pressed again. The average friction value is then displayed and printed.

(a) Limitation. The Mu-Meter Service Manual indicates that on consecutive section runs at 40 mph, there is a recording loss of approximately 6 ft of surface when the APU "compute" button is pressed. At this point no data is accepted by the APU for a period of about 100 msec. Since the APU provides only an average friction value for a particular test section, the strip chart recorder trace should still be utilized so that a graphical trace of the surface friction can be obtained.

(2) Remote Wheel Position Change Modifications. With the standard Mu-Meter, the rear wheel must be raised manually (to prevent operation of the recorder in nontest areas) and the starboard wheel must be moved to a position parallel to the port wheel (to prevent tire wear while testing is not in progress). The Remote Wheel Position Change modification affects these changes automatically from within the towing vehicle. There are several advantages to this type of modification. During rainfall, the operator does not need to leave the cab of the towing vehicle. There is a resultant increase in speed of operation. The Mu-Meter can be towed away from the test area without operation of the recorder or wheels in the test position.

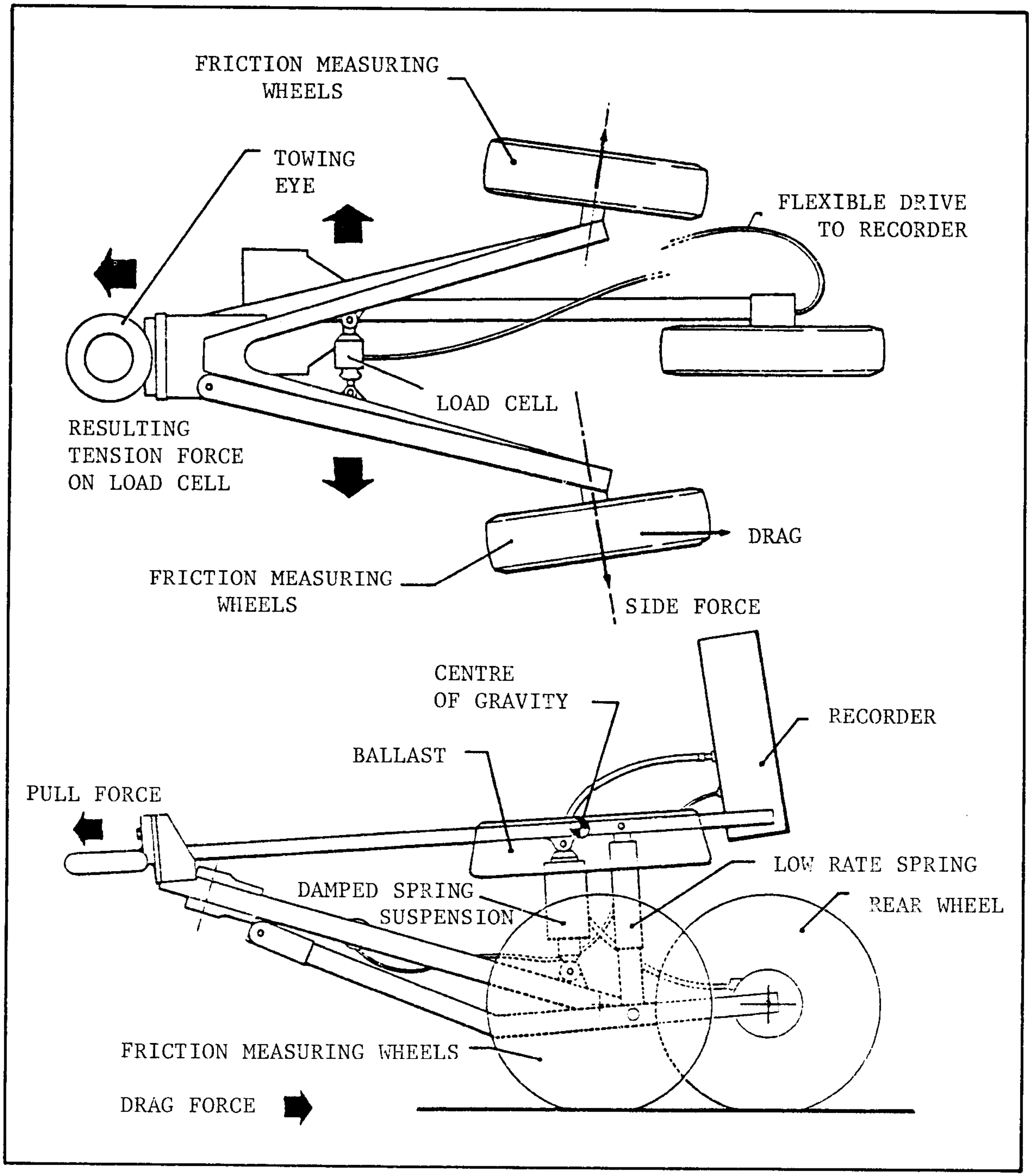


FIGURE 7

Diagram of the Mu-Meter (M.L. Aviation Co. Ltd., M.L. Mu-Meter Instruction and Servicing Manuals, Maidenhead Berkshire, England, 1375)

(3) Self-Watering System. The Mu-Meter Self-Watering System was designed to overcome problems encountered in artifically wetting the pavement to obtain wet surface friction characteristics. The self-watering system provides a known constant water depth for the test speed selected. This method of water placement is not affected by airflow behind the towing vehicle or by prevailing wind conditions. The self-watering system (Figure 8) basically consists of a pair of nozzles located just ahead of the test tires. Water is stored on the tow vehicle and pumped through the nozzles at a regulated rate. Maximum water storage capacity is around 200 gallons for a full size heavy duty pickup truck.

2. RUNWAY FRICTION TESTING PROCEDURE

a. Objectives. The objectives of runway friction testing are to:

-- Determine the potential for skidding or hydroplaning on runways.

-- Determine the magnitude or severity of potential hydroplaning problems.

-- Evaluate the drainage characteristics and the friction recovery relationship for runways.

As part of the friction testing work, a condition survey of the runway should also be performed. The condition survey identifies and rates pavement surface defects by a statistically based procedure, with the results expressed in terms of numerical condition ratings (weighted defect densities). These numbers can be used to determine priorities for maintenance and repair efforts. Procedures for conducting condition surveys are contained in NCEL, Field Procedures and Techniques for Conducting Naval and Marine Corps, Airfield Pavement Condition Surveys.

b. Equipment. The standard friction measurements will require the use of three main equipment items:

(1) Mu-Meter. The Mu-Meter is the friction measuring instrument which should be used for runway friction evaluations. The Mu-Meter is described in paragraph 3.1.

(2) Water Application Truck. A water application truck is used to apply water to the test section. For wetting of one 10 ft. by 1000 ft. test section, to a depth of 0.2 inches, a minimum capacity of 1500 gallons is required. This capacity requirement allows for leakage, wastage, etc. The water application truck should be equipped with a pump-force water system (independent of the vehicle drive train) and an operative pump pressure gauge used to maintain a constant water output. The tractor unit must be equipped with an operative engine tachometer in order to maintain a precise forward speed and a gearing axle ratio which will enable the truck to maintain a constant low forward speed under changing load conditions. Normally, the runway foamer at most Naval Air Stations meets these requirements.

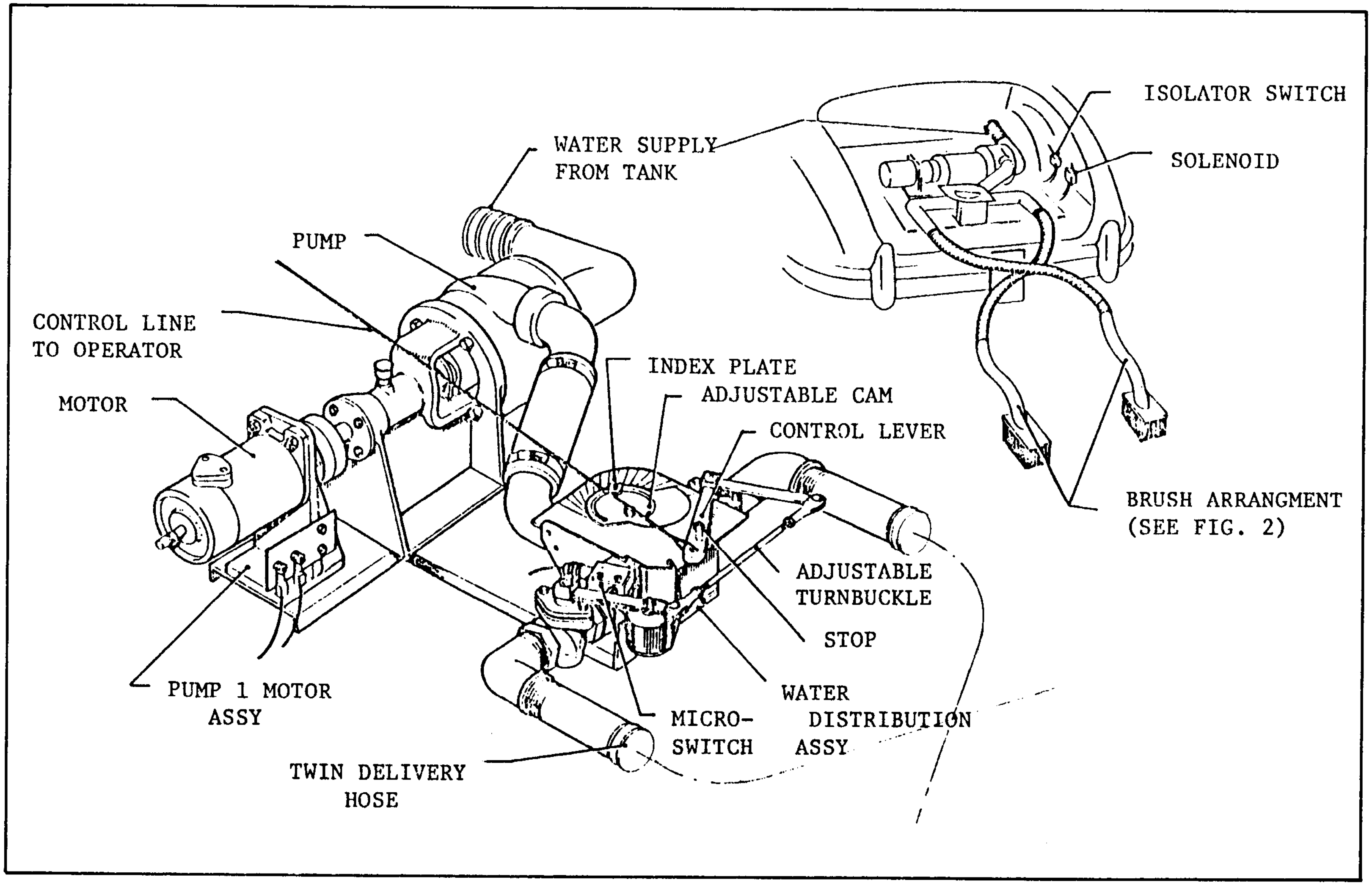


FIGURE 8

Xu-Meter Self-Watering System
(M.L. Aviation Co. Ltd., M.L. Mu-Meter Instruction and Servicing Manuals,Maidenhead, Berkshire, England, 1975)

(3) Slope Measurement Device. A slope measurement device is a 10 ft rectangular section with machinists levels attached in order to determine the percent of cross slope to the nearest 0.1 percent of the pavement surface. In the absence of this device a surveyors level and rod or other measuring technique which will yield transverse grades within 0.1 percent may be used.

c. Preliminary Test Arrangements. To achieve maximum cooperation and coordination, each Naval Air Station scheduled for survey should be officially informed in writing of the proposed test effort. The following items should be arranged for in advance:

(1) Runway Layout. Obtain a runway layout plan including the as-built pavement sections showing longitudinal and transverse grades. Obtain an up-dated construction and maintenance history for all runways to be surveyed.

(2) Support. Arrange for the required support from the activity. Activity support should include:

-- A base vehicle for the team chief to use during testing.
-- Flightline vehicle with driver to maintain radio control with the tower.
-- A water truck with a two-man crew.
-- Rapid water truck refill capability.
-- Station personnel to remove arresting gear cables on the day of the test.
-- A secure storage area for storage of the Mu-Meter and other equipment.

(3) Runway History. Arrange for interviews with appropriate Operations and Public Works personnel regarding any history of poor braking/hydroplaning incidents or mishaps. Ascertain the general runway drainage characteristics, rates of rubber accumulation, frequency of removal, pavement texture, and any other factors which may affect hydroplaning potential. If possible, arrange to obtain documentation of wet weather related aircraft incidents.

d. Test Procedures

(1) Gradient Measurements. Measurements should be made at each runway end and at each 500 foot station. Extra measurements may be made as deemed necessary. At each point to be measured, measure the longitudinal slope, then two lo-foot lanes each side of the centerline (total of 5 measurements). Observe how the straight edge lays on the pavement. If it is consistently supported at its ends for instance, there is a trough under it. This could be due to repetitive aircraft wheel passage and could be indicative of a water ponding area. Also be careful of extruded joint seal and dished concrete slabs which gives erroneous slope readings.

(2) Test Section Layout. The standard friction measurements are to be conducted on all in-service paved runways at least 5000 ft. in length. Within each runway, measurements are conducted on pre-selected sections 8 to 10 feet wide by 1000 feet long. A total of 5 to 7 test sections should be selected in the touchdown areas (rubber deposit areas> and the runway interior (primary braking area) based on the slope measurements and general observations. Choose the worst areas, not representative areas. Cross wind conditions will determine the selection of the central interior sections as water will be held at a greater depth on the up-wind side. The center line of the test sections should be placed at approximately the location of the aircraft wheel path. Test sections in the rubber deposit areas should begin approximately at the start of the rubber buildup. When one test section layout transverses both asphalt and concrete pavement areas, friction measuring procedures should be designed to obtain average Mu values for each pavement type. A representative test section layout is shown in Figure 9.

(3) Arresting Gear Removal. A 500-foot clear acceleration/deceleration space is needed at each end of the test section. Based on the test section layout, determine if any arresting gear needs to be derigged. Frequently, the derigging crew can be out to the runway in **10** minutes and the derigging operation takes about 5 minutes for most arresting gear.

(4) Mu-Meter Calibration. A standard calibration check is required on the Mu-Meter at the beginning of each day of testing and after each change of tires. Prior to the calibration check the tire pressure must be set at precisely 10 psi. The tire pressure should be periodically checked during the testing and maintained at 10 psi. The Mu-Meter is calibrated, using the standard calibration board in accordance with the manufacturer's procedures. Repeat the calibration procedure at least three times. The average reading with the standard calibration board should be 0.77. Any deviation from this value will require adjustment of the toed-out angle of the tires in accordance with the manufacturer's procedures.

(5) Water Truck Calibration. For purposes of standardization it is important that water application procedures be established and firmly adhered to. Friction values are sensitive to water depth and extreme care must be exercised in applying the proper amount of water with uniform distribution over the length of the test section. The required water depth is 0.2 inch, applied in two passes of the water truck at 0.1 inch per pass. The quantity of water required for 0.1 inch depth per 1000 foot section is 500 gallons for an 8 ft. spray bar; proportionally larger for longer bars.

Table 6 provides flow requirements for varying rates of speed with an 8 ft. wide spray bar for application of 0.1 inch of water. For other spray bar lengths the flow rates shall be increased in direct proportion to the length. To minimize inaccuracies due to speedometer readings and to assure the proper flow rate is applied, a calibration run must be made at each Air Station prior to operational testing.

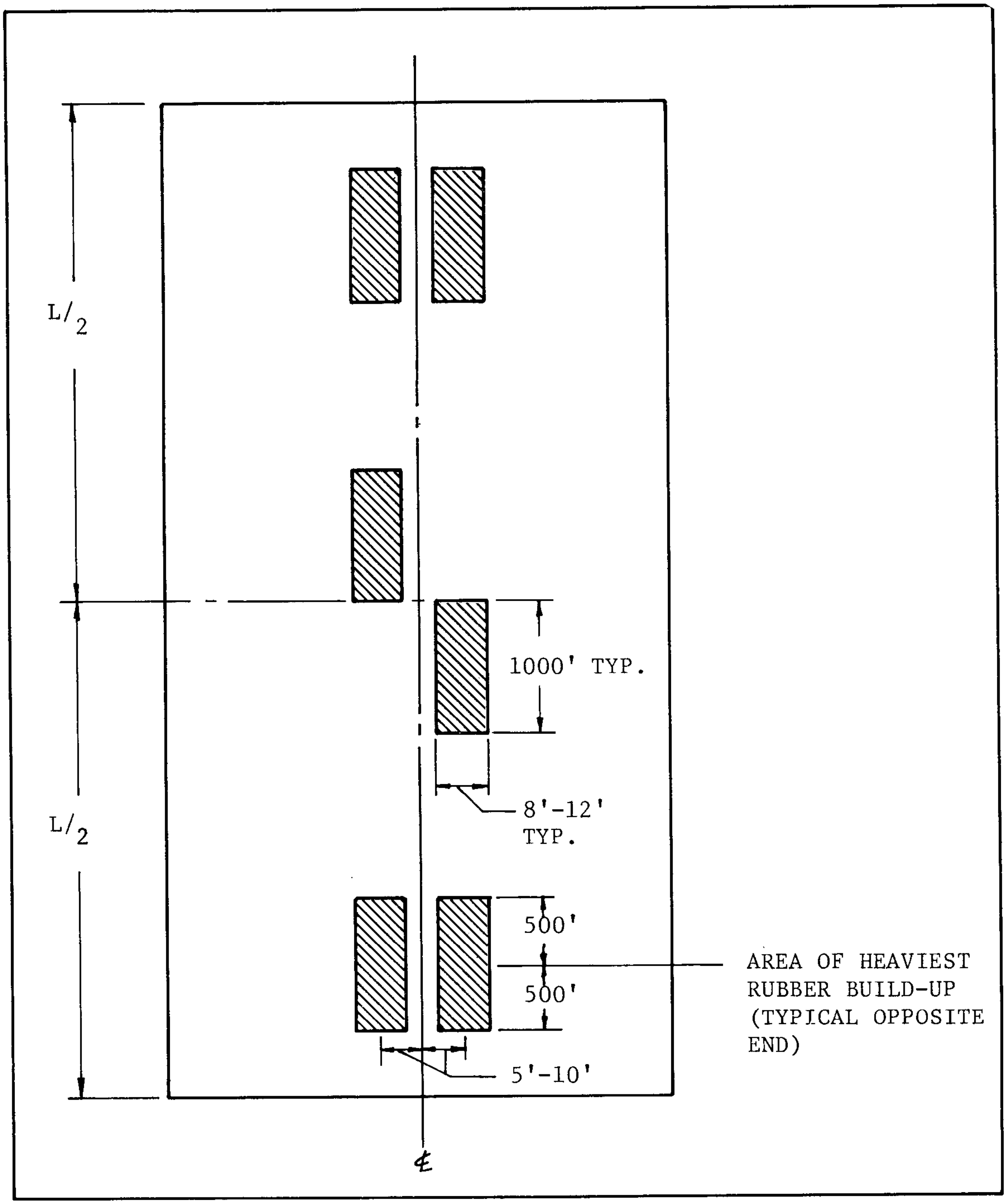


FIGURE 9

Typical Layout of Runway Test Sections

TABLE 6

Water Application Requirements for 0.1 Inch Depth

8 FOOT WIDE SPRAY BAR					
TRUCK SPEED				FLOW REQUIREMENT	
M.P.H.	Km.P.H.	FT./MIN	M/MIM.	G.P.M.	L.P.M.
		150	45.7	75	283.9
2	3	176	53.6	90	340.7
		200	61.0	100	378.5
3	5	264	80.5	130	503.8
		300	91.4	150	567.8
4	6	352	109.3	175	678.1
		400	121.9	200	757.0
5	8	440	134.1	220	852.5
		500	152.4	250	946.3
6	10	528	160.9	265	1026.9
		550	167.6	275	1040.9
7	11	616	187.8	305	1181.9
		650	198.1	325	1230.1
8	13	704	214.6	350	1356.3
		750	228.6	375	1419.4
9	14	792	241.4	395	1530.6
		850	259.1	425	1608.6
10	16	880	268.2	440	1665.3
		900	274.3	450	1703.3
11	18	968	295.0	485	1879.4
		1000	304.8	500	1892.5
12	19	1056	321.9	525	2034.4
		1100	335.3	550	2081.8
13	21	1144	348.7	570	2208.8
		1200	365.8	600	2271.0
14	23	1232	375.5	615	2383.1
		1300	396.2	650	2460.3
15	24	1320	402.3	660	2557.5

(6) Friction Testing

(a) Dry pavement friction testing. For dry pavement friction testing, one run in each direction will be made in each test section. Dry friction should be 0.65 or greater. If less than 0.65, the Mu-Meter calibration should be rechecked. The following sequence of events is recommended:

-- Enter the test section at 40 mph. Marks are made on the Mu-Meter tape with the event recorder to mark the beginning and end of a test section. Use two marks to mark the location of any change in pavement type. Upon completion of the run determine the integrated coefficient of friction from the remote read-out or Mu-Meter windows "A" and "B". Record the average value of Mu and mark the tape for section identification.

-- Repeat the procedure for the same test sections in the opposite direction.

-- Upon completion of a test section, record from the tapes the maximum and minimum values of Mu for both directions and "eyeball" the average values as a check on average values read from the remote read-out.

(b) Wet pavement friction testing. Mu-Meter measurements will commence immediately upon completion of the second pass of the water application truck. All water application and friction tests will be completed in one test section prior to starting any other test section. The measurements will be conducted at 40 mph. A minimum of 6 passes will be made successively, as the friction changes rapidly in the first few minutes. Two additional passes will be made at 20 and 30 minutes after wetting the test section. Where the pavement has reached a relatively dry state prior to completion of all measurements, the measurements should be terminated. The following additions should be added to the sequence of events noted in paragraph 3.2.d.(6)(a) for wet pavement friction testing.

-- Record with a stopwatch the time the water application truck begins the second pass. Record the time that the application truck leaves the test section. The average time in the test section is the "zero water time". The "zero water time" is the time from which all subsequent time measurements are made.

-- Immediately after the water truck has exited the test strip, the Mu-Meter should commence its first run in the test strip. Record the time for the Mu-Meter to enter and exit the test section, the average value of Mu, and mark the tape for section identification.

-- Immediately begin the second run in the direction opposite the first run. Record all times for entering and exiting the test section. Repeat the procedure for at least six successive runs and run up to 30 minutes from "zero water time".

e. Report Preparation. A runway skid resistance report will be prepared for each Activity surveyed. A suggested outline of the contents of the report is as follows:

(1) Introduction. Brief statement of the contents of the report.

(2) Purpose. Describe the intent of the friction measuring program.

(3) Equipment. Description of the Mu-Meter.

(4) Test Procedures. Describe the test procedures for slope measurements, water application, friction measurement, and condition surveys.

(5) Test Locations. Include a runway layout plan outlining the test sections.

(6) Test Results. Use tables, graphs, and charts to report the test results. Report values of Mu for all test runs, with interpretative emphasis on the first run after water application. For guidance in interpretation of the test results the scale shown in Table 7 has been adopted.

TABLE 7
Mu-Meter Ratings

(3 Minute Values)	Hydroplaning Potential	Action
Greater than 0.5	No hydroplaning problems expected	None required
0.4 - 0.5	Potential for hydro-planing exists for some aircraft under certain wet condi-tions	Plan corrective action
Less than 0.4	High probability for hydroplaning	Take corrective action

In addition to the data summary tables, provide appropriate plots of Mu-Meter results for the following:

(a) Friction versus distance. Plot the friction value versus distance trace for the full length of each test section for the first test run after wetting. This plot will display the variation of friction within the test section. Where possible, identify the pavement condition (i.e., ponding water, polished surface, etc.) wherever sharp dips in the trace occur.

(b) Friction versus time. Plot the average friction value versus time after wetting for each of the test sections. These graphs will display the natural drainage characteristics of the runway surface and the time required for the friction values to return to the dry condition.

(7) Conclusions/Recommendations. Include comments on the skid resistance properties, drainage characteristics, and visual condition of the runways surveyed. Interpret, where possible, the suspected causes and potential solutions to low friction values. Recommendations, firmly supported by the field data, for remedial measures such as rubber removal, leveling overlays, etc., may be included.

(8) Other. Provide data supplemental to the friction measurements. Included in the report should be (a) climatological data (precipitation, wind, temperature), (b) aircraft operations (numbers, type, percent runway usage), (c) construction and maintenance history.

REFERENCES
(Publications containing criteria cited in thus manual)

Government Agency Publications

Advisory Circular 150/5320-12, Methods for Design, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces, Department of Transportation, Federal Avaiation Administration, Washington, D.C., June 1975.

Advisory Circular 150/5370-10, Standards for Specifying Construction of Airports, Department of Transportation, Federal Aviation Administration, Washington, D.C., October 1974.

FAA-R-74-38: Field Performance of Porous Friction Surface Course; White, Thomas D., Federal Aviation Administration, Washington, D.C., April 1976.

NAVFACENGCOM DESIGN Manuals and Publications

Government agencies may obtain Design Manuals from the U.S. Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120. TWX: 710-670-1685, AUTOVON: 442-3321. The stock number is necessary for ordering these documents and should be requested from the NAVFACENGCOM Division in your area.

Non-Government organizations may obtain Design Manuals from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

DM-21 Airfield Pavements
DM-21.3 Flexible Pavement Design for Airfields

NAVFACENGCOM Guide Specifications (TS Series)

NAVFACENGCOM Guide Specifications are available free of charge from the U.S. Naval Publications and Forms Center, Philadelphia, PA 19120. TWX: 710-670-1685, AUTOVON: 442-3321.

TS-02613 Portland Cement Concrete Pavement for Roads & Airfields

TS-02674 Asphalt Slurry Seal

Other Agencies

ASTM Standards, American Society for Testing and Materials, Philadelphia, PA 19103, Annual Book of ASTM Standards

Part 14. Concrete and Mineral Aggregates
Part 15. Road, Paving, Bituminous Materials; Skid Resistance

C29 Test for Unit Weight and Voids in Aggregate

C88 Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
Cl17 Test for Materials Finer than No. 200 (75-mm) Sieve in Mineral Aggregates by Washing
Cl27 Specific Gravity and Absorption of Coarse Aggregate
Cl31 Test for Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine
Cl36 Test for Sieve or Screen Analysis of Fine and Coarse Aggregate

D242 Mineral Filler for Bituminous Paving Mixtures
D693 Crushed Stone, Crushed Slag, and Crushed Gravel for Dry- or Water-Bound Macadam Base Courses and Bituminous Macadam Base and Surface Courses of Pavements
D977 Asphalt, Emulsified
D1664 Coating and Stripping of Bitumen-Aggregate Mixtures
D2397 Cationic Emulsified Asphalt
D2419 Sand Equivalent Value of Soils and Fine Aggregate

E303 Measuring Surface Frictional Properties Using the British Pendulum Tester
E660 Accelerated Polishing of Aggregates or Pavement Surfaces Using a Small-Wheel Circular Track

Transportation Research Board, National Academy of Sciences, Washington, D.C. 20418, Transportation Research Record

#523 Skid Resistance, 1974
#622 Skidding Accidents, Pavement Characteristics, 1977

American Concrete Paving Association, Technical Bulletin No. 6, Interim Recommendations for the Construction of Skid Resistant Concrete Pavement, August 1969.

Texas Transportation Institute, Texas A&M University, College Station, Texas, Research Report 138-5, The Effects of Rainfall Intensity, Pavement Cross Slopes, Surface Texture, and Drainage Length on Pavement Water Depths, May 1971.

Ballentine, G.D., The Air Force Weapons Laboratory Skid Resistance Research Program, 1969-1974; AFWL-TR-74-181, Air Force Weapons Laboratory, May 1975.

Duggan, L.F., Effectiveness, Skid Resistance, and Antihydroplaning Potential of Porous Friction Courses, Airport Operators Council International, Washington, D.C.

Jones, M.P., Approach, The Hazards of Hydroplaning, U.S. Naval Safety Center, July 1978.

M.L. Aviation Co., Ltd., ML Mu-Meter Instruction and Servicing Manuals, Maidenhead, Berkshire, England, 1975.

NCEL, Field Procedures and Techniques for Conducting Naval and Marine Corns, Airfield Pavement Condition Surveys, October 1972.

National Cooperative Highway Research Program, NCHRP Synthesis of Highway Practice 14, Skid Resistance, Highway Research Board, 1972.

Tomita, H. and J.B. Forrest, Porous Friction Surfaces for Airfield Pavements, AFWL-TR-74-177, Air Force Weapons Laboratory, May 1975.

Williams, J.H., Analysis of the Standard USAF Runway Skid Resistance Tests, AFCEC-TR-75-3,Air Force Civil Engineering Center, Tyndall Air Force Base, Florida, May 1975.

Yager, T.J., W.P. Phillips, and W.B. Horne, A Comparison of Aircraft and Ground Vehicle Stopping Performance on Dry, Wet, Flooded, Slush, Snow, and Ice-covered Runways, NASA-TN-D-6098, Langley Research Center, National Aeronautics and Space Administration, November 1970.

APPENDIX A

METRIC CONVERSION FACTORS

3/4 in	=	19 mm
3/8 in	=	10 mm
70 lbs/cu ft	=	1120 kg/m^3
6 in	=	150 mm
100 lbs	=	45 kg
10 in	=	254.0 mm
5 in	=	127.0 mm
340°F	=	171°c
200 ft	=	60 m
1.5 in/hr	=	38 mm/hr
0.045 in	=	1.14 mm
0.02 in	=	0.5 mm
100 ft	=	30 m
0.015 ft/ft	=	0.005 m/m
0.098 in	=	2.49 mm
0.045 in	=	1.14 mm
1.79 in/hr	=	45 mm/hr
0.167%/100 linear ft	=	.167%/30.5 linear m
3000 ft	=	915 m
10 ft	=	3.0 m
140 ft	=	43 m
l/4 in	=	6 mm
l-1/4 in	=	32 mm
l-1/8 in	=	29 mm
2 in	=	50 mm
l/16 in	=	2 mm
l-1/2 in	=	40 mm
75 ft	=	23 m
3 in	=	75 mm
2 ft	=	610 mm
1 in	=	25.4 mm

50 °F	=	10 °C
1500 ft	=	457 m
3 ft	=	l m
4 in	=	100 mm
l/8 in	=	3 mm
l/2 in	=	13 mm
0.016 in	=	0.41 mm
5000 psi	=	34 MPa
8000 psi	=	55 MPa
500 ft	=	152 m
13 ± lbs/sq yd	=	70 ± 10 kg/m^2
40 mph	=	60 km/hr
6 ft	=	1.8 m
200 gal	=	757 L
250 psi	=	1724 kPa
6 in	=	152 mm
1,000 ft	=	305 m
1500 gal	=	5778 L
5,000 ft	=	1524 m
8 ft	=	2.4 m
10 psi	=	69 kPa
0.2 in	=	5 mm
0.1 in	=	2.5 cm
500 gal	=	1893 L
5 ft	=	1.5 m
12 ft	=	3.7 m

APPENDIX B

METHOD OF TEST FOR Kc SURFACE CONSTANT

1. Scope. This method furnishes a measure of the surface capacity and absorption of the aggregate passing the 3/8-inch (10 mm) sieve and retained on the No. 4 sieve for use in determining the asphalt content in porous friction courses.

2. Special Apparatus-Material

   A. Metal funnel, top diameter 3-l/2 inches (88.9 mm), height 4-l/2 inches (114.3 mm), orifice l/2 inch (12.3 mm), with a piece of No. 10 sieve soldered to the bottom of the opening.

   B. Round tin pans, 4-l/2 inches (114.3 mm) in diameter, 1 inch (25.4 mm) deep.

   C. S.A.E. No. 10 lubricating oil.

3. Procedure

   A. Quarter out 105 g. representative of the passing 3/8 inch (10 mm) and retain No. 4 sieve material.

   B. Dry sample on hot plate or in 230°F±9°F (ll0°C+5°C) oven to constant weight and allow to cool.

   C. Weigh out 100.0 g and place in funnel.

   D. Completely immerse specimen in S.A.E. No. 10 lubricating oil for 5 min.

   E. Drain for 2 min.

   F. Place funnel containing sample in 140°F (60°C) oven for 15 min. of additional draining.

   G. Pour sample from funnel into tared pan, cool, and reweigh sample to nearest 0.1 g. Subtract original weight and record difference as percent oil retained (based on 100 g of dry aggregate).

4. Calculation of Bitumen Ratio

   A. Use Figure B-l for determination of K_c.

      (1) If specific gravity for the aggregate is greater than 2.70 or less than 2.60, apply correction to oil retained, using formula at top of chart in Figure B-l.

(2) Start at the bottom on chart in Figure B-l with the corrected percent of oil retained, follow straightedge vertically upward to intersection with the diagonal line, hold point, and follow the straightedge horizontally to the left. The value obtained will be the surface constant for the retained fraction and is known as "K_c".

B. The asphalt content based on the dry weight of the aggregate is determined from the following equation:

Percent asphalt by weight of aggregate = $2K_c + 4$

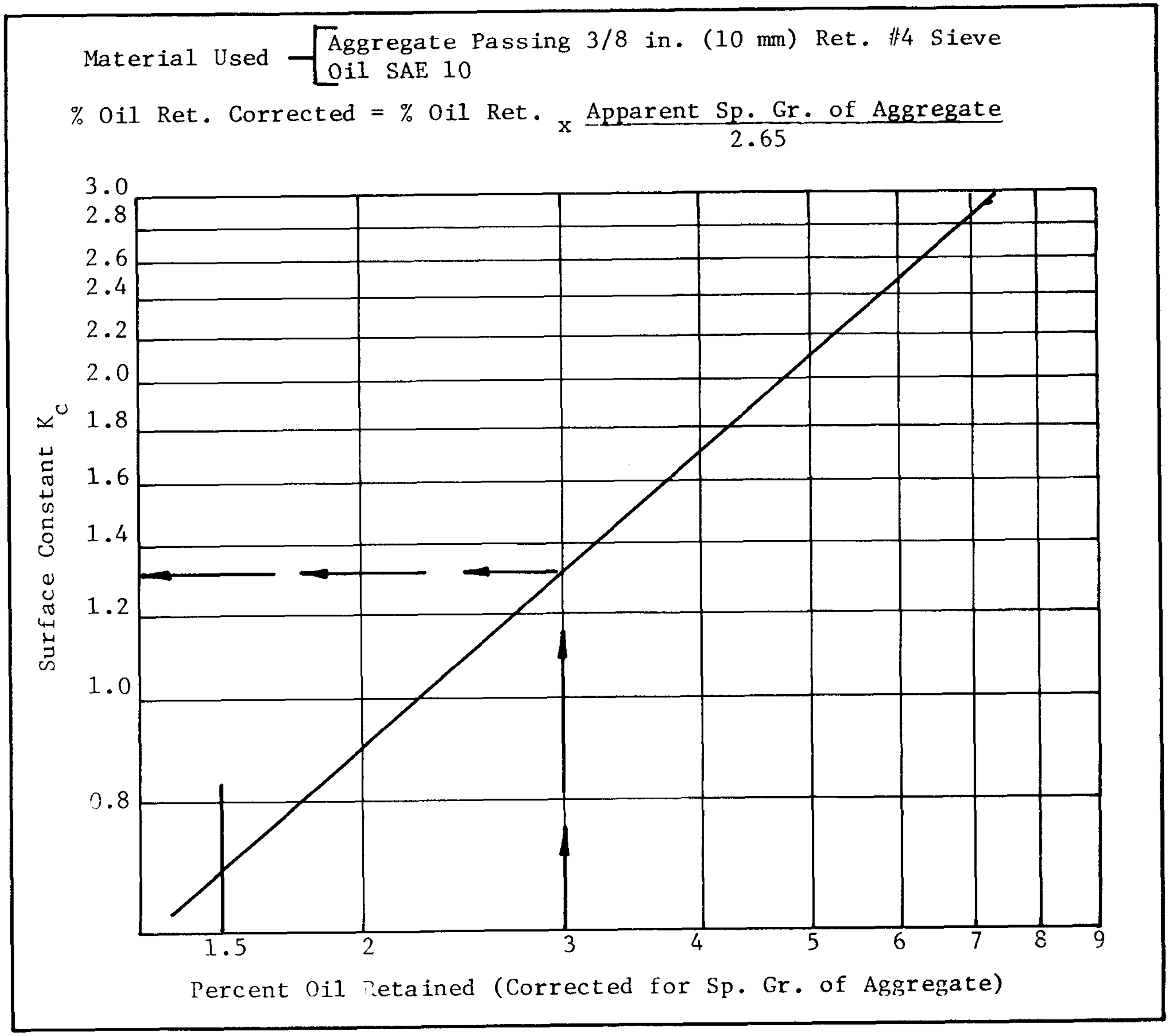


FIGURE B.1

Chart for Determining $_c$ from Coarse Aggregate Absorption

APPENDIX C. NASA GREASE-SMEAR TECHNIQUE FOR MEASURING PAVEMENT SURFACE TEXTURE DEPTH

1. GENERAL. To obtain an average texture depth, representative samples should be taken over the entire runway surface. The number of samples required will depend on variations in the surface texture. Descriptions of equipment, methods of measurement, and computations involved in the NASA Grease-Smear technique are as follows.

2. DESCRIPTION OF EQUIPMENT. The equipment required is shown in Figure C.1. On the left in Figure C.l is shown the tube which is used to measure the volume of grease, either fifteen cubic centimeters or one cubic inch. On the right is shown the tight-fitting plunger which is used to expel the grease from the tube, and in the center is shown the rubber squeegee which is used to work the grease into the voids in the runway surface. The sheet rubber on the squeegee is cemented to a piece of aluminum for ease in use. Any general purpose grease can be used. As a convenience in the selection of the length of the measuring tube, Figure C.2 gives the relation between the tube inside diameter and tube length for an internal tube volume of 15 cubic centimeters or 1 cubic inch. The plunger can be made of cork, or other resilient material to achieve a tight fit in the measuring tube.

3. METHOD OF MEASUREMENT. The tube for measuring the knownvolume of grease is packed full with a simple tool such as a putty knife, being careful to avoid entrapped air, and the ends are squared off. A general view of the texture measurement procedure is shown in Figure C.3. The lines of masking tape are placed on the pavement surface about 10 centimeters or 4 inches apart. The grease is then expelled from the measuring tube with the plunger and deposited between the previously placed lines of masking tape. It is then worked into the voids of the runway pavement surface with the rubber squeegee, being careful that no grease is left on the masking tape or the squeegee. The distance along the lines of masking tape is then measured and the area that is covered by the grease is computed.

4. COMPUTATION. After the area is computed, the following equations are used to calculate the texture depth.

$$(1)\ \text{Texture Depth (m)} = \frac{10 \times \text{Volume of Grease (cu. cm.)}}{\text{Area Covered by Grease (sq. cm.)}}$$

$$(2)\ \text{Texture Depth (in)} = \frac{\text{Volume of Grease (cu. in.)}}{\text{Area Covered by Grease (sq. in.)}}$$

$$(3)\ \text{Average Texture Depth} = \frac{\text{Sum of Individual Tests}}{\text{Total Tests}}$$

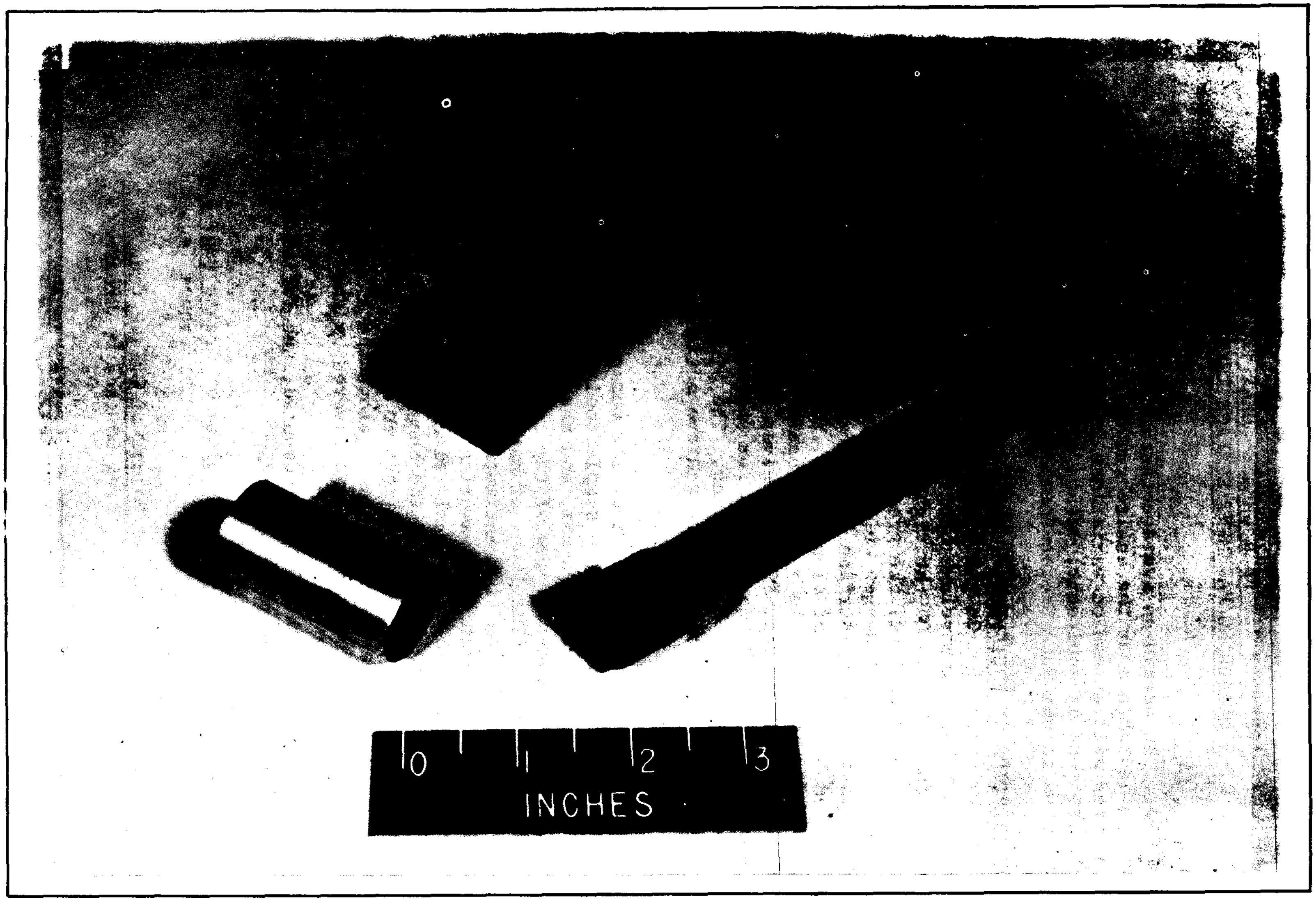


FIGURE C.1

Grease-volume measuring tube, plunger, and rubber squeegee

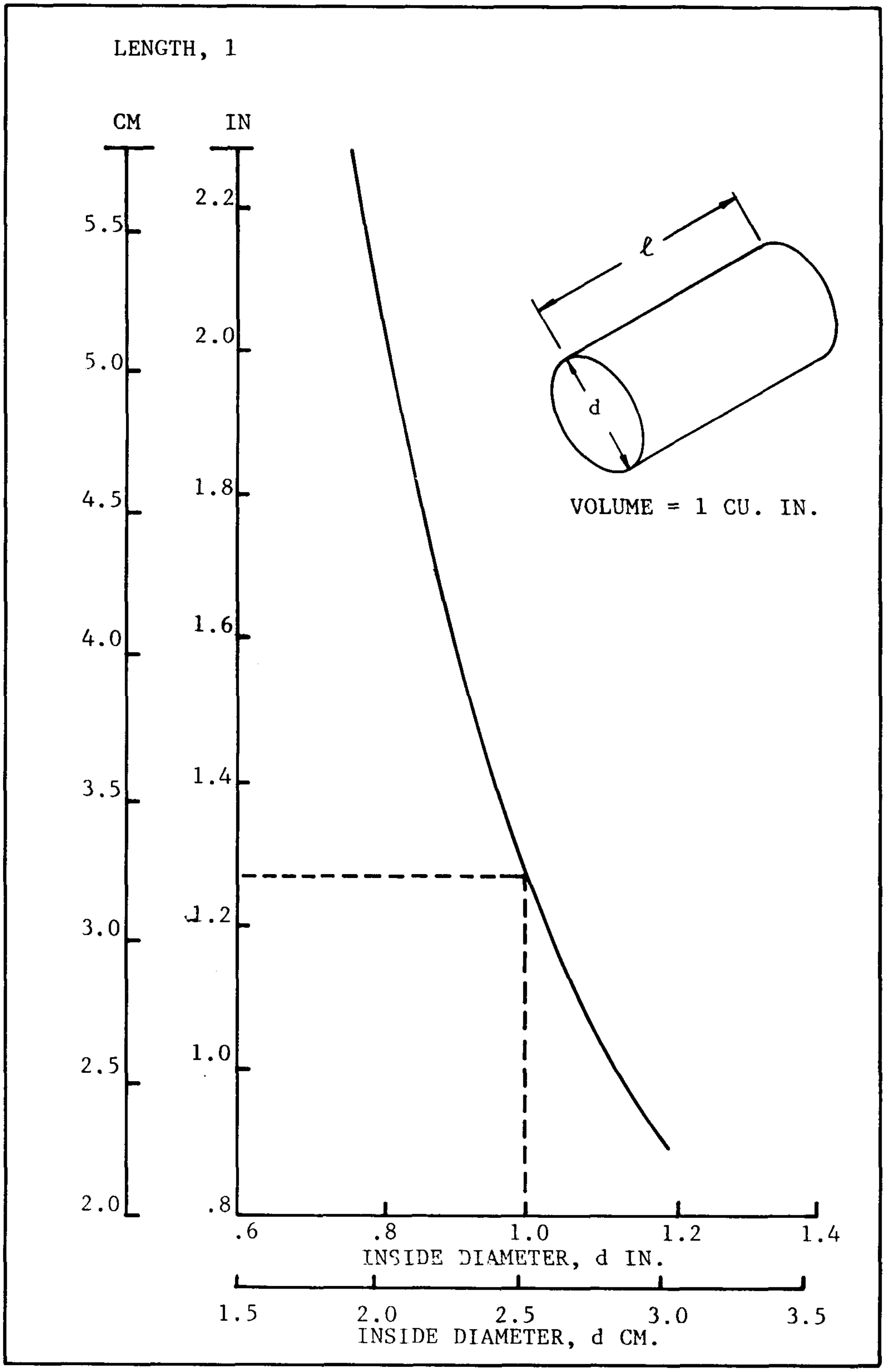


FIGURE: C.2

Measuring tube dimensions to measure
one inch or fifteen cubic centimeters